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THE STRUCTURE OF COMPLEX ATOMS AND THE CHANG OF MASS AND WEIGHT INVOLVED IN THEIR FORMATION

By William D. Harkins and Ernest D. Wilson
KENT CHEMICAL LABORATORY, UNIVERSITY OF CHICAGO

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A study of the atomic weights referred to hydrogen as unity shows that for the series of elements from helium to fluorine the average deviation from a whole number is 0.09 units, which is smaller than would be expected if the atomic weights were wholly the result of accident. However, the average deviation for the first 27 elements (0.21) is almost as great as would be expected as the result of chance (0.25 units). This, on first sight, does not seem to accord well with the numerical form of Prout's hypothesis, that these atomic weights should be whole numbers. If now the atomic weights referred to oxygen are considered, the remarkable relation is found that the numbers are exceedingly close to whole numbers as a rule. In order to save space these relations may be considered in the form of the results of calculations of probability. The chance that the sum of the deviations from whole numbers for the 27 lighter elements should be as small as it is when hydrogen is taken as 1 is found to be one chance in ten, when the method used for the calculation is of the form known as De Moivre's problem, and when the probable errors in the atomic weights are taken into account. In contrast with this it is found that there is only about one chance in fifteen million that the sum of the deviations from whole numbers of the atomic weights on the oxygen basis should be as small as it is.

This might seem to indicate that the atoms other than hydrogen are built up from units different from hydrogen and of a weight 1.000, while hydrogen has a weight 1.0078 (on the oxygen basis); but this would involve the existence of two kinds of particles with masses very nearly the same, and gives the additional difficulty that the atomic weights are not exact multiples of 1, which indicates that if the particle from which the atoms are built has a weight of nearly 1, this weight must vary somewhat from atom to atom. Attempts have been made to explain the discrepancy as the result of a variation in the number of negative electrons, but this method is neither in accord with recent theories of atomic structure, nor does it seem to agree with the fact that the atoms are neutral electrically.

If the assumption is made that the other atoms are hydrogen complexes, then it is found that in the formation of the complex there must result a change of weight which is in general negative in sign. The percentage decrease in weight may be called the packing effect, and the average value of this effect for the 27 lighter elements in 0.77%. The magnitude of this effect is nearly constant, as is shown by the value 0.77 for helium, while for the six elements from boron to sodium the packing effects are 0.77, 0.77, 0.70, 0.77, 0.77, and 0.77%. Since the value of the packing effect is -0.77% for oxygen, and this is the average packing effect of the 27 elements as well as the value of the effect for a considerable number of the different atoms, it is seen that the use of a whole number as the atomic weight of oxygen makes allowance for this effect and so gives to the other elements atomic weights which are whole numbers or very nearly whole numbers.

In order to determine a cause for this decrease in weight which must result if the other atoms are built up from the nuclei of hydrogen atoms as units, it will be well to consider if this effect may not be due to the overlapping of the fields of the charged particles which unite to form the *nucleus* of the complex atom. Recent work shows that this nucleus is extremely small. Rutherford, from data on the scattering of alpha particles in passing through thin gold leaf, has calculated the *upper* limit of the nucleus of the gold atom as 3.4×10^{-12} cm., and Darwin found the similar value for hydrogen to be about 0.8×10^{-13} cm., which is of the order of size of the negative electron as usually considered. If the gold nucleus is built up of hydrogen nuclei this would mean that it would contain about 197 hydrogen nuclei and 118 negative electrons in its extremely minute volume, if the idea of van den Broek and Moseley[1] that the positive charge on the nucleus is equal to the atomic number is used for the calculation. Thus over 300 particles would be contained in a volume which according to Rutherford's calculation has a radius of only 3.4×10^{-12} cm. as its upper limit of value. It must be emphasized that in this paper only the electrons contained in the nucleus of the atom are the ones which are considered, and that the distance of the external electrons, sometimes considered as of the order of the assumed radius of the atom as about 10^{-8} cm., has absolutely nothing to do with the packing effect.

The simplest case for an actual nucleus which could be calculated, is that of helium, which may be assumed to contain four positive particles and two negative electrons. However, the arrangement of these particles is not known, so the solution will be given for the case of a single positive and a single negative electron. That a change in mass will result if these two particles are brought very close together, is suggested by Lorentz,[2] but he calculates neither the sign nor the magnitude of the effect, nor does he indicate how the calculation may be made. The symbols used are **G** = electromagnetic momentum per unit volume, **H** = magnetic intensity vector, **E** = electric intensity vector, **S** = Poynting's vector for magnetic flux, c is the velocity of light, and **[AB]** represents the vector product.

Now $\mathbf{G} = [\mathbf{EH}]/c = \mathbf{S}/c^2$, and for the field due to a system of charges

$$\frac{[\mathbf{EH}]}{c} = \frac{\left[\left(\sum_i \mathbf{E}_i\right)\left(\sum_j \mathbf{H}_j\right)\right]}{c} = \frac{\sum_i [\mathbf{E}_i\mathbf{H}_i]}{c} + \frac{\sum_{(ij)} [\mathbf{E}_i\mathbf{H}_j]}{c}$$

where the summation $\Sigma_{(ij)}$ is the vector product of each i with each j. The first summation gives the electromagnetic momentum which would be due to the particles if their fields did not overlap, and the second term gives the effect of the overlapping of the fields. This may be called the "Mutual electromagnetic momentum," and is designated by $\overline{\mathbf{G}}$.

For point charges $E_1 = \dfrac{(1 - u^2)e_1}{4\pi r^2(1 - u^2 \sin^2 \theta_1)^{3/2}}$. Let $(1 - u^2) = K^2$ and $(1 - u^2 \sin^2 \theta_1) = \beta_1^2$. The transverse component of E due to the two particles 1 and 2 is

$$E_t = \frac{K^2 e}{4\pi}\left\{\frac{\sin \theta_1}{r_1^2 \beta_1^3} \pm \frac{\sin \theta_2}{r_2^2 \beta_2^3}\right\}$$

where the sign is positive if the charges have the same sign, and *negative if they are of opposite sign.* As only the longitudinal component of the vector **G** is desired, only the transverse component of **E** is needed. Then $H = uE \sin \phi/c$, where ϕ = the angle between E and the direction of u.

If E_t is used, $\phi = 90°$, and $H = u\,(E_1 \sin \theta_1 \pm E_2 \sin \theta_2)/c$. Hence

$$\mathbf{G} = \frac{[\mathbf{E}_t\mathbf{H}]}{c} = \frac{u}{c^2}(E_1 \sin \theta_1 \pm E_2 \sin \theta_2)\,(E_1 \sin \theta_1 \pm E_2 \sin \theta_2),$$

$$\text{and } \overline{\mathbf{G}} = \pm \frac{2u}{c^2}\int E_1 E_2 \sin \theta_1 \sin \theta_2 d\tau = \frac{2uK^4e^2}{c^2(4\pi)^2}\int \frac{\sin \theta_1 \sin \theta_2}{r_1^2 r_2^2 \beta_1^3 \beta_2^3} d\tau.$$

Now $r^2\beta^2 = r^2 - u^2(r^2 \sin^2 \theta)$ and $r^2 \sin^2 \theta = y^2$. Let $a = \frac{1}{2}$ distance between e_1 and e_2. Neglecting all terms in u^2, and placing $d\tau = 2\pi y dy dx$, we have

$$\overline{\mathbf{G}} = \pm \frac{uK^4e^2}{8c^2\pi^2}4\pi \int_0^\infty\!\!\int_0^\infty \frac{y^3 dy dx}{\sqrt{\{[(x - a)^2 + y^2]\,[(x + a)^2 + y^2]\}^3}}$$

which is obtained by making use of the symmetry of the equation. The evaluation of this integral gives the value $1/2a$ so $\overline{G} = \pm uK^4e^2/(4\pi ac^2)$. The mass represented by this value of $\overline{G}$ is $\Delta m = \pm e^2/(4\pi ac^2)$ where Δm is the change of mass due to the overlapping of the fields of the electrons. Now the longitudinal mass is $m_1 = e^2/(6\pi c^2 R)$ where R = radius of the electron. By division $\Delta m/m_1 = 3R/2a$, where a equals one-half the distance apart of the electrons.

Taking R as the radius of the positive electron, and -0.77% as the packing effect, it is seen that in this simple case the distance apart of the positive and the negative electrons would be 400 times the radius of the positive electron. However, the system used for the calculation does not correspond to any actual atom, but if it is considered that the gold nucleus is *smaller* than corresponds to a radius of 3.4×10^{-12} cm., as Rutherford calculates, then when it is considered that the large number of positive and negative electrons contained in this space must make up a very complex system, undoubtedly with a special structure, it is evident that the distances of the electrons as calculated to give the observed packing effect, is of the right order of magnitude to give a gold nucleus of the kind supposed by Rutherford's theory.

The Hydrogen-Helium System. Fajans,[3] Soddy,[4] Russell,[5] von Hevesy,[6] and Fleck,[7] have proved that when a radioactive element ejects an alpha particle, found by Rutherford to have a mass of 4 units, and to give ordinary helium gas, the new substance produced has different properties and a different valence from the parent material. The change is such that the new element lies two groups to the left in the periodic table and therefore has an atomic number and a valence with values two less than before. Now that this relation has been found to apply to elements of high atomic weights, the question arises as to whether the same relations hold for the lighter atoms which have not been found to give an appreciable alpha disintegration. If they do, then the atomic weights of the elements of even atomic number could best be found by beginning with helium, and adding a weight of 4 for each step of two atomic numbers, and by proceeding in the same way beginning with lithium for the odd numbered elements. This gives:

Atomic number even = 4 8 12 16 20 24 28 32
Atomic number odd = 7 11 15 19 23 27 31 35

which are on the whole the correct atomic weights. The system obtained in this way may be best represented in the form of a periodic table as in the table.

When given in this way it is seen that the atomic weights not only follow the helium system derived from the behavior of the radioactive elements, but in addition, after this has been applied it is seen that there is a great regularity in the number of hydrogen atoms, H_3, which must be included to give the atomic weights of the elements of odd atomic number.

The table gives an explanation of the fact that the atomic weight of argon is higher than that of potassium while its atomic number is lower. This is seen to be due to the general tendency for the increment between the third and fourth series to take the value 5He, and in this sense it is the potassium and calcium which are irregular in behavior, and not the argon. In this part of the table there is seen to be a tendency to add 2He instead of 1He for one step between elements of even atomic number.

SYMBOLIC REPRESENTATION OF THE ATOMIC WEIGHTS ACCORDING TO THE HELIUM SYSTEM DERIVED FROM THE BEHAVIOR OF THE RADIOACTIVE ELEMENTS IN THEIR ALPHA DISINTEGRATIONS

H DETD. = 1.0078

GROUP	0	1	2	3	4	5	6	7	8	
Series 2	He	Li	Be	B	C	N	O	F		
	He	$He+H_3$	$2\,He+H$	$2\,He+H_3$	3 He	$3\,He+2\,H$	4 He	$4\,He+H_3$		
Calc.		7.	9.	11.	12.	14.	16.	19.		
Detd.	4.	6.94	9.1	11.	12.	14.01	16.	19.		
Series 3	Ne	Na	Mg	Al	Si	P	S	Cl		
	5 He	$5\,He+H_3$	6 He	$6\,He+H_3$	7 He	$7\,He+H_3$	8 He	$8\,He+H_3$		
Calc.	20.	23.	24.	27.	28.	31.	32.	35.		
Detd.	20.	23.	24.3	27.1	28.3	31.02	32.07	35.46		
Series 4	A	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co
	10 He	$9\,He+H_3$	10 He	11 He	12 He	$12\,He+H_3$	13 He	$13\,He+H_3$	14 He	$14\,He+H_3$
Calc.	40.	39.	40.	44.	48.	51.	52.	55.	56.	59.
Detd.	39.88	39.1	40.07	44.1	48.1	51.	52.	54.93	55.84	58.97

Inctement from series 2 to series 3 = 4 He.
Increment from series 3 to series 4 = 5 He. (For K and Ca = 4 He.)
Increment from series 4 to series 5 = 6 He.

If a weight of 4 is added for each increase of 2 in the atomic number, then the average increase of the atomic weight per atomic number should be 2, and that this is in accord with the facts is shown by the atomic weights of neon and calcium. These elements have the atomic numbers 10 and 20, and the atomic weights, $10 \times 2 = 20$, and $20 \times 2 = 40$. The equation[8] which gives the atomic weights of the lighter elements is $W = 2n + \frac{1}{2} + \frac{1}{2}\ (-\ 1)^{n-1}$, where n is the atomic number. In order to include the heavier elements it is necessary to insert another term, the meaning of which will be considered in a later paper, to account for the tendency of the increment of weight to become greater as the atomic weight increases, as follows: $\mathrm{W} = 2\ (n + n') + \frac{1}{2} + \frac{1}{2}\ (-\ 1)^{n-1}$.

That no system can explain the atomic weights of the heavier elements, unless account is taken of the fact that different series of elements exist, is evident when it is considered that the isotopes of lead, radium B, and lead from radium, differ in atomic weight by eight, or by 4%, and even in the case of some of the lighter elements that a part of the irregularity may be due to the existence of isotopic forms is indicated by the discovery by Thomson and Aston that neon, formerly supposed to have an atomic weight of 20.2, consists of two isotopes of atomic weights 20 and 22. It has been proved by Fajans and others, as has been mentioned, that the helium system holds for the heavy radioactive elements; in this paper it is shown that it also holds for the 27 lighter elements, which would seem to make it almost certain that it holds for the other elements when the proper allowances are made for variations in packing effect, and differences of series.

For the elements from helium to iron the average value of the packing effect is 0.78 units, which is, so far as the accuracy of the atomic weights allows us to determine, the same as the decrease in weight which would occur if four hydrogen atoms were to be transformed into one of helium. This means that if any element of higher atomic weight is built up entirely of helium atoms, then, on the average, the decrease in mass is practically entirely due to the primary formation of the helium atoms, and not at all to the aggregation of these into the heavier atoms. From this point of view an atom composed entirely of helium units would have extreme instability in relation to its disintegration into helium units, in comparison with its instability with reference to a hydrogen decomposition. Such an atom in a radioactive transformation should lose alpha particles very much more readily than hydrogen nuclei, in fact, if it is remembered that even the alpha decomposition does not occur appreciably for many of the known elements, it will be seen that it is doubtful if such an atom would ever give a detectable hydrogen disintegration.

If the elements of higher atomic weight are built up exactly according to the special system presented in the table, according to which the members of the even numbered groups are in general aggregates of helium alone, then since all of the radioactive elements which are *now known* to give a simple alpha disintegration, belong to even numbered groups, they could not be expected to give hydrogen upon disintegration. Thus one of the chief objections to the theory that the atoms are hydrogen complexes, which is based on the fact that up to the present time no hydrogen has been detected as the product of any radioactive change, is seen to be not contrary to, but rather in accord with the theory as here presented. However, the value of this idea is lessened by the fact that there is no evidence that the exact relations between the composition of the odd and even groups as found for the elements of smaller atomic weight hold so far into the system as the radioactive elements. The general form of the system indicates at least that the heavy atoms contain more helium than independent hydrogen units, and this seems in accord with the fact that uranium loses alpha particles in eight steps without any apparent loss of a hydrogen nucleus.

The stability with which the hydrogen nuclei which are not contained in helium groups, but which generally occur in threes (H_3 in the table), are built into the complex atom is not in general indicated with any degree of accuracy, but in the case of lithium it seems to be great, for lithium shows the extremely large packing effect equal to 1.57%, which might seem doubtful if it were not for the extreme care taken by Richards and Willard[9] in the determination of the atomic weight of lithium. The atomic weight of hydrogen used in these papers (1.0078) is probably not in error[10] by so much as one part in 5000.

The hydrogen-helium system here presented is entirely in accord with, but independent of, the astronomical theory that the order in which the elements appear in the stars is first nebulium, hydrogen and helium, then such of the lighter elements as calcium, magnesium, oxygen, and nitrogen, and finally iron, and the other heavy metals, although in the present system it has not been found necessary to include nebulium. Some of the nebulae give bright line spectra of nebulium, hydrogen and helium; such Orion stars as those of the Trapezium give lines for hydrogen and helium; while those that are more developed show magnesium, silicon, oxygen and nitrogen, and some of the other low atomic weight elements in addition. Bluish white stars such as Sirius give narrow and faint lines for iron, sodium, and magnesium, and the solar stars give a much weaker hydrogen spectrum, and many more and stronger lines for iron and the heavy metals.[11] The astronomical theory that the heavier elements are thus formed from those of smaller atomic weight is of extreme interest, but the evidence for it is somewhat uncertain, since it is possible that it is the difference in the density of the different elements which is the effective factor in causing the spectra to appear in the order in which they are found to occur. The relative brightness of the different lines varies greatly, such lines as the calcium H and K lines being extremely strong, and this also interferes with the determination of the order of the appearance of the elements in the stars. On the other hand the evidence presented in these papers seem to give some support to the theory of the evolution of the heavier atoms from those which are lighter, but the hydrogen-helium system here presented has the support of much better evidence than that for atomic evolution from the standpoint of astronomy alone.

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[3] K. Fajans, *Physik. Zs., Leipzig*, **14**, 131 and 136.

[4] F. Soddy, *Chem. News, London*, **107**, 97; *Jahrb. Radioakt.*, **10**, 188.

[5] Russell, *Chem. News, London*, **107**, 49.

[6] Von Hevesy, *Physik. Zs., Leipzig*, **14**, 49.

[7] Fleck, *Trans. Chem. Soc.*, **103**, 381 and 1052.

[8] Rydberg, *Zs. anorg. Chem., Hamburg*, **14**, 86–7.

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[10] W. A. Noyes, *Textbook of Chemistry*, p. 72.

[11] Hale, *The Study of Stellar Evolution.*

HUNTINGTON'S CHOREA IN RELATION TO HEREDITY AND EUGENICS

By C. B. Davenport

STATION FOR EXPERIMENTAL EVOLUTION, CARNEGIE INSTITUTION OF WASHINGTON

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It is now generally conceded that predisposition plays an important rôle in mental disorder but the views as to the nature of its part are very diverse and hazy. Some investigators conclude that there is an inheritance of a particular type of mental trouble, while others conceive that only a general psychopathic constitution is inherited. Again a difference of view maintains as to the nature of the recognized mental 'diseases'—by some these are regarded as distinct 'entities,' manifestations of a single, indivisible, disturbing factor. Others conceive of them as syndromes or chance associations of symptoms. Even those who hold the latter view would perhaps except as the one clear case of a neuropathic entity the condition known as 'Huntington's Chorea.' This chorea is defined by the following traits: (1) persistent tremors of the head, appendages and trunk; (2) the onset of such tremors in middle or late life; (3) the progressive nature of the tremors; and (4) progressive mental deterioration. These characters are frequently found together; is their association a necessary one?

A study of four family complexes in eastern Long Island, south-western Connecticut, south-central Connecticut and eastern Massachusetts which show nearly a thousand cases of Huntington's chorea yields the